A Voice and Ear for Telephone Measurements

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An artificial voice and ear have been developed which are sufficiently close simulations of the real voice and ear in their principal physical attributes to justify their use in both shop and laboratory tests of telephone transmitters and receivers.

The artificial voice and ear have certain advantages in that they can be exactly specified and reproduced and can be used in determining physical characteristics of instruments which are difficult or impossible to obtain with real voices and ears.

THE performance of telephone transmitters and receivers is dependent not only upon their physical characteristics but also upon the reactions of the users to these instruments. Observations of the results obtained by subscribers under known conditions of practical telephone use take both these factors into consideration. Tests of this kind, however, are not suited to the needs of laboratory development and study of instruments where data regarding their physical characteristics are required. In such instances data, to be of greatest value, should be taken under conditions which include those factors of actual service having an important bearing on the performance of the instruments.

Among the most important of such factors are the voice and ear. For making many of the laboratory tests, therefore, it has been necessary to employ actual human voices and ears in order to insure that all of their physical characteristics have been included in the test. This procedure, however, due to uncontrollable variations in individuals, requires a large expenditure of time and effort to insure the precision desired. Furthermore, certain instrument tests, such as response-frequency characteristics, are either impossible or difficult to make with the real voice or ear.

These disadvantages, inherent in the use of the human voice and ear, have been recognized for a long time. Numerous attempts have been made to employ voice and ear substitutes for instrument testing, and in cases where uniformity of instruments rather than their design has been of primary importance, as in shop acceptance tests, such substitutes have been of great value. That their use in engineering design problems has not been more extensive has been due to the inability to make them meet certain fundamental requirements.

It has been the aim, therefore, in the design of the artificial voice and ear to be described, to overcome previous objections to the use of

such substitutes so that they may be used with confidence in general testing and physical measurement of telephone transmitters and receivers. The requirements which an artificial voice and ear must meet to insure proper performance are outlined below.

Requirements for an Artificial Voice

An ideal artificial voice must be able to reproduce human speech without introducing any change in frequency, amplitude or directivity over the entire range of intensities possible in speech. Furthermore, it should react to changes in acoustic load in the same manner as does the human voice under ordinary conditions. Such requirements, of course, must be reduced to a more specific and practical form to enable the construction of a physical piece of apparatus.

It is useful to consider the artificial voice as consisting of two parts, the mouth and the source of power. Practical considerations point immediately to the use of some form of electro-acoustic transducer for the mouth, and any of several sources of electrical power. In the production of speech there is required as a source of power either a high quality transmitter or a phonograph record and reproducing system. For purposes of physical measurement and analysis, a source of single-frequency power, such as an oscillator, is needed.

If it be assumed that the frequency composition of the actual human voice is automatically included with either of the sources of speech mentioned, and that proper frequency weighting will be introduced in the single-frequency source when desired by means of suitable electrical networks, the practical requirements for the artificial mouth may then be stated specifically as follows:

(1) It should introduce no amplitude distortion within the range of speech frequencies.
(2) It should be capable of delivering an acoustic output without non-linear distortion over the range of intensities possible for the human speaking voice.
(3) The distribution of the sound field about the mouth at every frequency and distance should be the same as that of the human mouth.
(4) The introduction of objects such as transmitters in the sound field should react on the output of the mouth and distort the field in the same way as they do when introduced in the field of the human mouth.
(5) It should be completely specifiable and reproducible as well as constant in performance.

Requirements for an Artificial Ear

In considering a substitute for the human ear, the general requirement is that it shall respond, as does the human ear, to sounds of various frequencies, amplitudes and lengths of duration. Furthermore, its reaction on the source of sound, whether that sound be produced by a receiver held against it or by a source at a distance from it, shall be the same as that of the human ear.

As in the case of the artificial voice, the artificial ear may conveniently be considered as consisting of two parts, the ear coupler and the measuring equipment. Based on the above general considerations, the ear coupler should meet the following more specific requirements:

(1) It should have the same impedance at every audible frequency as a real ear, either in the open air or with the receiver held to it.

(2) The pressures developed in the ear coupler should be the same at every audible frequency as the pressure developed in a real ear.

For the measuring equipment, the requirements are as follows:

(1) For steady state conditions it should be capable of giving an indication at every audible frequency proportional to the pressure in the coupler over a range of pressures as great as that experienced by a real ear.

(2) It should respond to sound of short duration as does a real ear.

(3) It should be possible to change the response to various frequencies in any manner required by means of suitable electrical networks.

(4) It should respond to complex sounds as does the real ear.

The artificial ear should be completely specifiable, reproducible, and constant in performance.

At the present time it is not possible to meet rigidly all of these requirements, either for an artificial voice or ear. Development work has progressed to a point where it can be stated that the requirements have been met sufficiently well to enable the production of both an artificial voice and ear which are close simulations of the real voice and ear and which will be satisfactory as substitutes in almost all of the laboratory or shop tests for which a real voice and ear have been largely used.

Description of the Artificial Voice

The schematic arrangement of the artificial voice referred to is shown in Fig. 1. As indicated, electrical energy may be supplied

from any one of several sources through the electrical network and amplifier to the electro-acoustic transducer. For single-frequency measurements a heterodyne oscillator provides a convenient means for obtaining the desired testing currents. As a source of speech, advantage can be taken of recent developments in phonograph technique which make it possible to record and reproduce speech practically without distortion.[1] This affords a very satisfactory source of speech for the artificial voice. In certain special instances where it is desired to make measurements with human voices under closely controlled conditions, a high quality transmitter is used as the input element of the artificial voice.

To insure proper operation under both steady-state and transient conditions the electrical network employed in the artificial voice is of

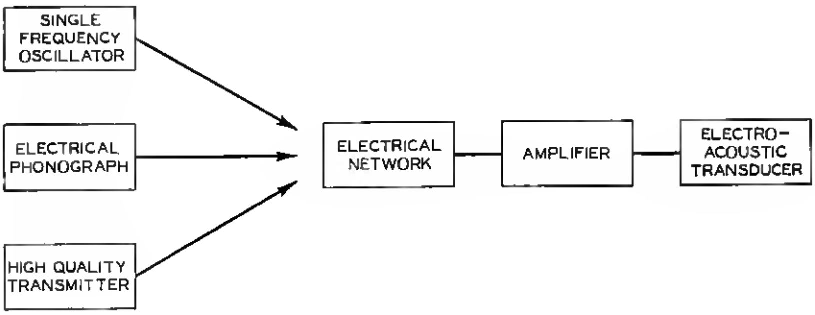


Fig. 1—Schematic arrangement of artificial voice.

the constant-resistance type.[2] In this network is included compensation for deviation from uniformity of response of the electro-acoustic transducer. Additional compensation may be provided in case the input to the artifical voice is from a source of constant output with frequency and it is desired to weight the single frequency output of the artificial voice in accordance with the distribution in speech [3] of pressure with frequency.

The amplifiers employed have high gain and high output capacity. They provide, without introducing distortion, the maximum amount of electrical energy that may be required to obtain the desired acoustical output from the artificial mouth.

[1] "Vertical Sound Records—Recent Fundamental Advances in Mechanical Records on Wax." Presented by H. A. Frederick at Swampscott, Mass., Oct., 1931, before the Soc. of Motion Picture Engineers.

[2] "Distortion Correction in Electrical Circuits with Constant Resistance Recurrent Networks," Otto J. Zobel, *Bell System Technical Journal*, July, 1928.

[3] "Some Physical Characteristics of Speech and Music," Harvey Fletcher, *Bell System Technical Journal*, July, 1931.

The unit employed as an artificial mouth is shown in Fig. 2 mounted on a stand in such a manner that it may be rotated through an angle of approximately 180° as a matter of convenience in certain types of testing. It is a modification of a loud speaking receiver of large power capacity.[4] As one of the requirements in the design of a substitute for

Fig. 2—Artificial mouth.

the human voice is that the distribution of the sound field of the artificial voice must be similar to that of the human voice, it is necessary to make the opening or sound radiating surface of the artificial mouth comparable in size with that of the human mouth. To meet this need the horn coupling ordinarily associated with this

[4] "A High Efficiency Receiver of Large Power Capacity for Horn-Type Loud Speakers," E. C. Wente and A. L. Thuras, *Bell System Technical Journal*, January, 1928.

type of receiver is removed, the throat insert of the receiver modified and a simple structure mounted in place of the horn coupler having an opening effectively that of the human mouth. In this structure is mounted an acoustic-resistance element. This has a mechanical resistance [5] of approximately 41.0 mechanical ohms per cm.[2] and below 5000 c.p.s. a reactance of less than 10 per cent. There is mounted on the structure replacing the horn coupler, a guard ring which serves as a reference plane for measurements of distance between the artificial mouth and instruments under test. The location of this reference plane has been empirically determined so as to correspond to the plane of the lips of a human mouth.

At low frequencies the radius of the opening of the mouth is small compared to the wave-length. Hence in effect a point source of sound is approached. Under these conditions the radiation resistance is small. As the frequency increases the radiation resistance increases until the wave-length has decreased to a value approximately three times the radius of the opening. At this frequency and above, the radiation resistance is approximately constant at about 41.0 ohms per cm.[2] The output impedance of the artificial mouth is high with respect to the radiation impedance at low frequencies. Inasmuch as the impedances are not matched except at the higher frequencies the output power should be approximately proportional to the radiation resistance. However, this relationship is modified by the resonances of the instrument. The acoustic resistance reduces these resonances and also serves to reduce the reaction on the artificial mouth which might arise by placing an instrument close to and directly in front of it.

The response-frequency characteristic of the mouth measured at the guard ring is shown in Fig. 3. In order that this response may be uniform over the important speech frequency range of 100 to 7500 c.p.s. the characteristic shown in Fig. 3 is equalized with the network indicated in Fig. 1. The resulting response of the artificial voice is shown in Fig. 4.

Another important requirement is that the artificial mouth shall be capable of delivering without non-linear distortion sound outputs corresponding to what may be termed loud talking for human beings. Because it is desirable to operate at frequencies as low as 100 c.p.s. it is necessary to supply a comparatively large amount of electrical energy to the artificial mouth. To accomplish this an amplifier has been employed as indicated in Fig. 1 which makes it possible to obtain

[5] "Methods of High Quality Recording and Reproducing of Music and Speech Based on Telephone Research," J. P. Maxfield and H. C. Harrison, *Bell System Technical Journal*, July, 1926, p. 506.

sound pressures of 16 bars at the plane of the guard ring at all frequencies between 100 and 7500 c.p.s. without appreciable harmonics. Speech may be transmitted about 15 db above the average intensity employed in commercial telephone conversations without noticeable distor-

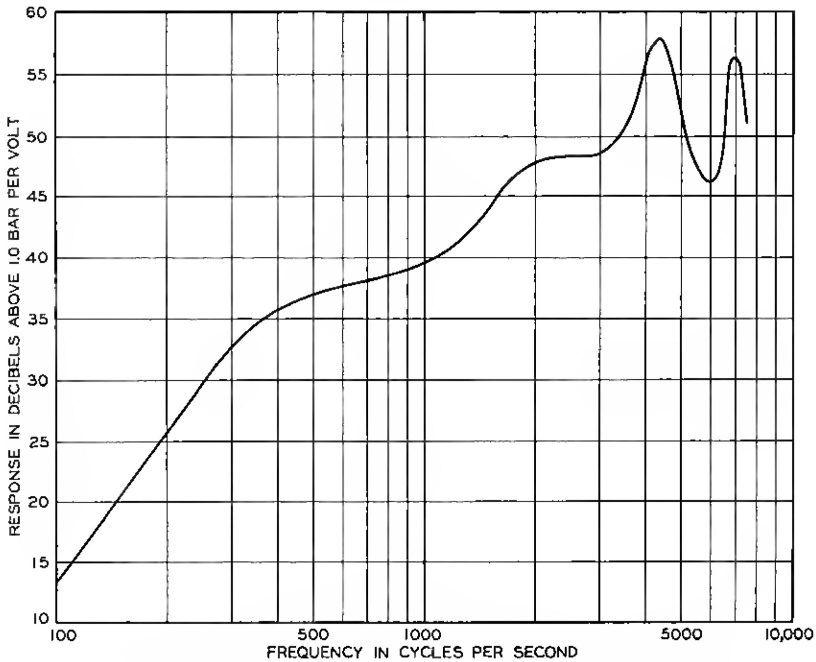


Fig. 3—Response-frequency characteristic of electro-acoustic transducer without equalizer.

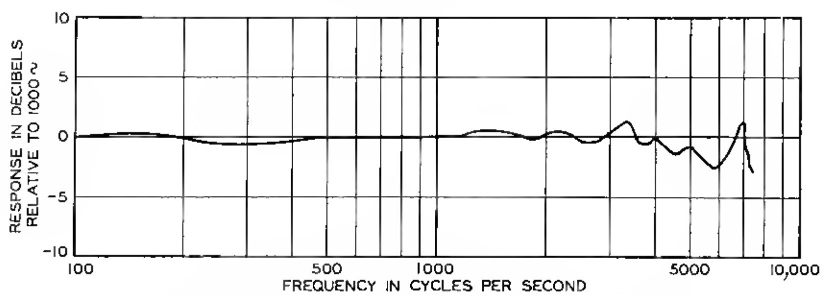


Fig. 4—Response-frequency characteristic of artificial mouth.

tion. Very few conversations are carried on at an intensity greater than this.

Measurements have been made of the magnitude of the harmonics present in the output of the artificial voice under conditions of high

sound pressure at 100 c.p.s. where maximum amplitudes of vibration are encountered. Only odd harmonics are present, the greatest in magnitude, the third, being about 15 db below the fundamental at the highest pressure used. At other frequencies or lower intensities, the harmonics are of even less importance. At the average intensity employed in telephone conversations no appreciable harmonics whatever are present. The results of these measurements are shown in Fig. 5.

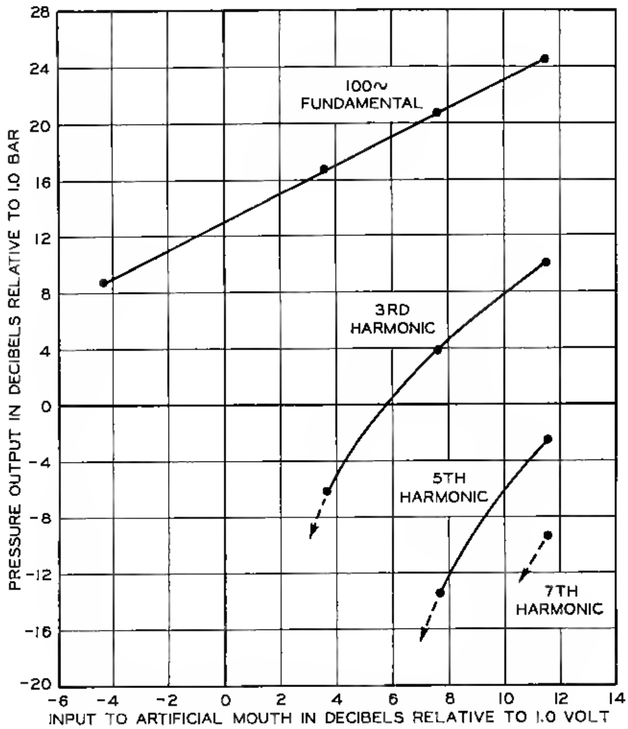


Fig. 5—Harmonics in output of artificial mouth.

It has been mentioned that the sound field distribution of the human and artificial voices should be alike. One method of determining agreement in this respect has been to measure the output of several different types of transmitters when the instruments were placed at various distances from both the artificial mouth and the human mouth. Eight persons, four men and four women, were employed in the actual voice tests, to call the testing phrases, "Joe took father's shoe bench out" and "She was waiting at my lawn." These phrases include all of the important speech sounds and are

brief and easy to say. The speech output of these same individuals calling the above phrases was recorded by the process mentioned.[1] After adjusting the output of the artificial voice for the close talking position with a condenser transmitter,[6] tests were made on the various instruments interspersing both instruments and voices to reduce testing errors and minimize changes in instrument characteristics between tests. The results of individual tests on a given type of instrument with both the human and artificial voices varied over approximately the same range. The average results for all tests for each type of instrument for each distance and for both the human and

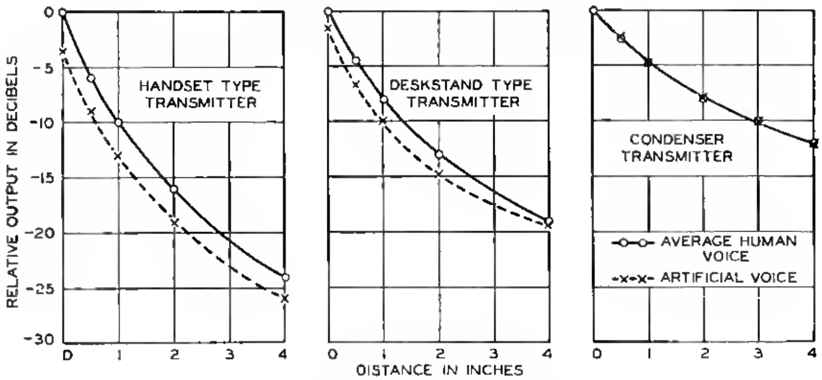


Fig. 6—Distance loss characteristics.

artificial voices are shown in Fig. 6. These data show reasonably close agreement between the artificial voice and human voice, both as regards the general level and slope of the distance loss characteristics. In the practical application of the artificial mouth to telephone instrument studies the minor discrepancies shown may be minimized by the use of correction factors. A further investigation is being made of the sound field distribution of the artificial mouth in comparison with that of human mouths.

Tests were made to determine the effect on telephone instruments of the size and shape of the artificial mouth. Response-frequency measurements were made, a deskstand and a handset transmitter being used, each modified to include in the plane of the diaphragm a small condenser transmitter. The latter was used in order that any variation of carbon instruments might be eliminated. Sound pressure was obtained from each of four types of artificial mouth. Three of these employed a long pipe with an inside diameter of about 0.7 inch.

[1] Loc. cit.
[6] "Electrostatic Transmitter," E. C. Wente, *Phys. Rev.*, May, 1922.

In one case no baffle or reflecting surface of any kind was used at the pipe opening. In the other cases it was terminated (1) in a replica of a human head molded of soft rubber (2) in an 8-inch square baffle. The fourth type used was the artificial mouth with acoustic resistance shown in Fig. 2. The variation in pressure measured for these various conditions is shown on Fig. 7. It will be noted that except for the

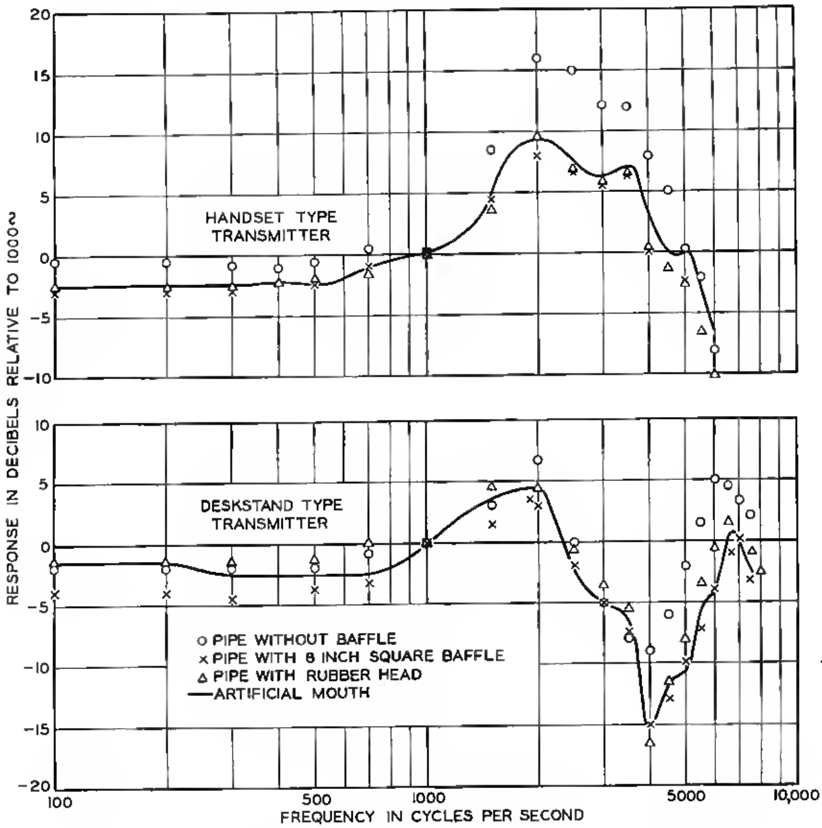


Fig. 7—Effect on station transmitters of variation in size and shape of artificial mouth.

extreme condition of the pipe without termination, good agreement is obtained for the various response-frequency characteristics, indicating that the shape of the artificial mouth is not critical provided the opening is of the proper order of magnitude and is effectively in a baffle commensurate with the size of the human head. The measurements described above were made with the plane of the mouthpiece of the instruments in a representative position with respect to the plane

of the mouth opening. To determine the effect of increasing the distance between the transmitter and the mouth, measurements were made with the deskstand type of instrument with results as shown in Fig. 8.

Measurements were made of the distortion of the sound field from each of the four types of mouth mentioned which was caused by the introduction of different types of transmitter in the field. The effects were measured immediately to one side of the mouthpiece. It will be seen from Fig. 9 that for frequencies below 2000 cycles there is good agreement for all types of mouth and both types of instrument. Above 2000 c.p.s. variations appear, but in general the largest differences occur as before for the extreme form of artificial mouth, namely, the pipe without termination.

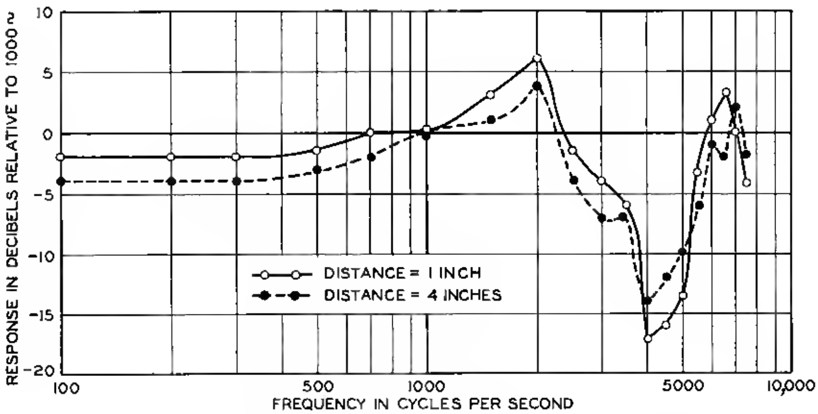


Fig. 8—Effect on station transmitters as distance from mouth is varied.

Summarizing the results obtained with the artificial mouth described, although the general requirements have not been completely satisfied, a rather close approximation has been realized. The response-frequency characteristic does not vary more than $\pm$ 1.0 db from 250 to 3000 c.p.s. nor more than $\pm$ 2.0 db from 100 to 7500 c.p.s. The mouth is capable of delivering an output of an intensity equivalent to loud talking without appreciable non-linear distortion. The distribution of the sound field is similar to that of the real mouth. As judged by tests on several different forms of mouth of quite different sizes and shapes, the indications are that the introduction of objects in the sound field of the artificial mouth chosen distorts that field in about the same manner as occurs with the real mouth. Speech reproduced by the artificial voice sounds natural. Comparative

articulation tests of direct speech from an individual and its reproduction by the artificial voice agree within a few per cent. The design can be definitely specified and reproduced with accuracy and it is rugged in structure and constant in performance.

General experience in the use of this artificial voice over about a year's time has indicated that it may be used satisfactorily in forms of transmitter testing which have heretofore required the human voice.

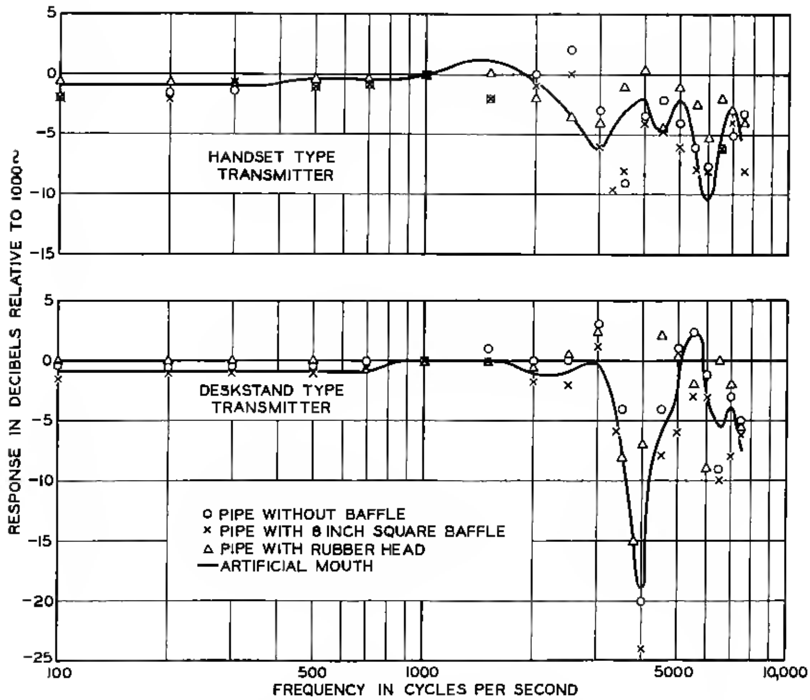


Fig. 9—Effect of introducing station transmitters in sound field of artificial mouth.

The Artificial Ear

The human ear is limited in its utility generally to relative or comparative measurements, and is not well adapted for measurement of absolute pressure or velocity. At best, measurement with real ears is a laborious procedure. In general, it has been found necessary to take a large number of observations with many ears, since a measurement with one ear is unreliable. One of the principal reasons for this unreliability is the difficulty not only of securing a particular coupling of a receiver held to the ear, but of duplicating this coupling in subsequent measurements.

The output of a receiver coupled to the ear is governed by several factors, among which are: enclosed volume, leakage around the cap, constriction of the ear canal and the yielding of walls and tympanum. Resonances in the enclosed volume are also generally present, associated with the dimensions of the chamber. The effects of the acoustic load of an ear coupled to a receiver are, in general, increased damping, higher resonant frequency and a dropping off of the receiver response at low frequencies. The receiver response also shows peaks due to resonances in the enclosed chamber.

Largely as a matter of convenience, couplers of simple construction imposing a stiffness load have been frequently used for receiver calibrations. It has been recognized that calibrations made in this way do not agree with the performance realized when the receiver is held to the ear and this has led to the development of an artificial ear which will permit the measurement of receivers of any type under conditions closely simulating those under which they are used.

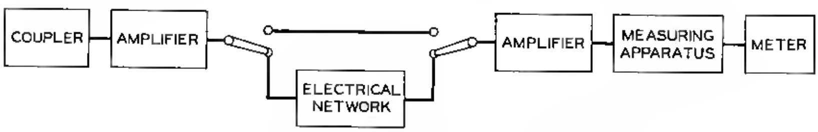


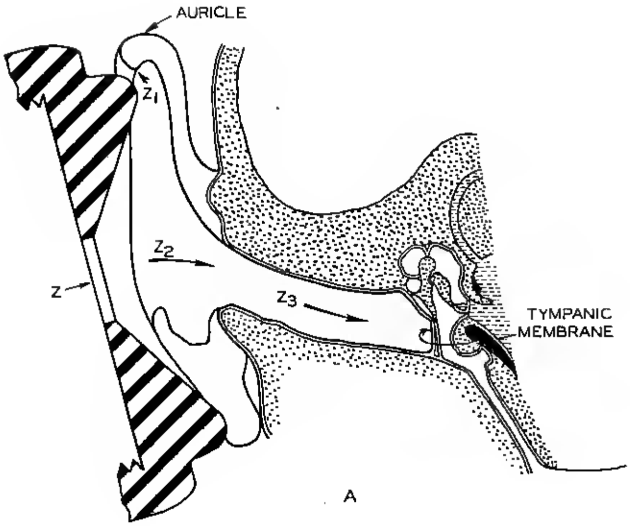
Fig. 10—Schematic arrangement of artificial ear.

The schematic arrangement of this artificial ear is shown in Fig. 10. It comprises: a special coupling device designed to present the same acoustic load to a receiver as does a typical human ear, a small condenser transmitter serving as the measuring element in the coupler, and means for amplifying and measuring the voltages generated by the condenser transmitter. For certain purposes arrangements are provided for introducing an electrical network of the constant-resistance type [2] having a response-frequency characteristic corresponding to that of the equal loudness curve [7] of human hearing at the desired sensation level.

The coupler is shown in Figs. 11 and 12. The cap of the receiver under test rests upon a molded soft rubber insert which has the internal contour of the auricle. Soft rubber was selected because of its yielding qualities which are of importance in two respects: it permits the receiver under test to be sealed to the coupler without the aid of such substances as petroleum jelly, and it can be readily molded to have the desired shape. In this rubber insert is an acoustic leak consisting

[2] Loc. cit.

[7] "A Direct Comparison of the Loudness of Pure Tones," B. A. Kingsbury, *Phys. Rev.*, April, 1927.



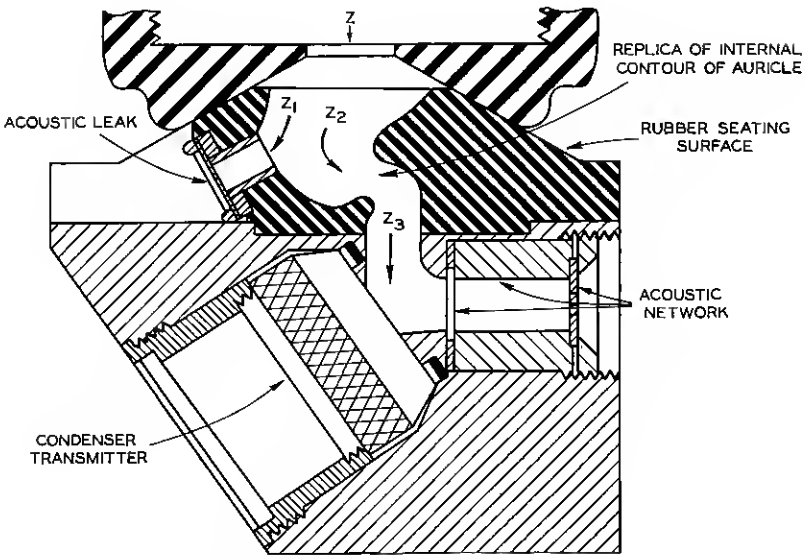


Fig. 11—Sectional views of human ear and artificial ear coupler.

of a tube terminated by an acoustic resistance. The purpose of this leak, which has both mass and resistance, is to simulate the leak between a receiver cap and a typical human ear. The molded rubber insert is attached to a rigid structure in which a chamber has been

Fig. 12—Artificial ear coupler.

provided to simulate the size and, to some extent, the shape of the auditory canal of a human ear. The diaphragm of the small condenser transmitter has been placed in the wall of this chamber to measure the pressures developed. The chamber is terminated by an acoustic network having mass, stiffness and resistance components of

the same order of magnitude as those observed looking into the auditory canal of a human ear. In considering Fig. 11, it should be noted that, due to the irregular contour of the auricle, one sectional drawing cannot adequately portray the shape of the opening in the molded soft rubber insert.

The box shown in Fig. 12, in which the artificial ear is mounted, houses a two-stage amplifier for use with the small condenser transmitter. The mechanical structure around the receiver is used for centering it on the coupler and to hold it in position at a definite pressure, the force, of course, always exceeding the weight of the receiver.

The magnitude of the impedance (Z) indicated in Fig. 11 was measured looking through the aperture of a conventional type of receiver cap held in a normal manner to the ear by each of 14 men. As might be expected, wide variations were observed between individual ears, particularly for the lower frequencies. Considerable variation was also observed on repeated tests on an individual. Table I shows the magnitude and range for both the resistance and reactance

TABLE I

ACOUSTIC IMPEDANCE OF EARS LOOKING THROUGH APERTURE OF RECEIVER CAP

f	Observed Range of Measurements for 14 Male Human Ears		Artificial Ear			
	Resistance	Reactance	Resistance		Reactance	
			(1)	(2)	(1)	(2)
100....	1 to 70	−300 to +24	21	16	−295	+15
300....	1 to 80	−195 to +60	14	56	−112	+59
400....	1 to 200	−115 to +92	11	149	− 72	+ 5
800....	1 to 107	−111 to +10	15	15	− 45	−45
1200....	3 to 18	− 36 to +30	11	11	− 24	−24
2300....	1 to 21	− 21 to −5	5	5	− 15	−15

(1) With no leak.
(2) With typical leak between receiver cap and ear.

components of the acoustic impedance observed in the measurements made at several frequencies. Supplementing these data is Fig. 13 which shows the acoustic resistance and reactance for typical human ears with and without a leak between the receiver cap and the ear, together with similar data on the artificial ear. It will be noted that the various impedance curves for comparable conditions of the human and artificial ears are quite similar in shape. There is, however, some discrepancy in the magnitudes of the impedance for comparable

conditions. In view of the large range in the impedance values obtained for different individuals and at different times the discrepancies indicated are of doubtful importance. In this connection it should be noted that a wide range in impedance values could be obtained readily on the artificial ear merely by changing the constants of the acoustic networks. In view of the fact that a fixed condition of the artificial ear is desirable for many practical purposes the chief requirement as regards the impedance characteristics under discussion is that they closely approximate the impedance characteristics of a typical ear.

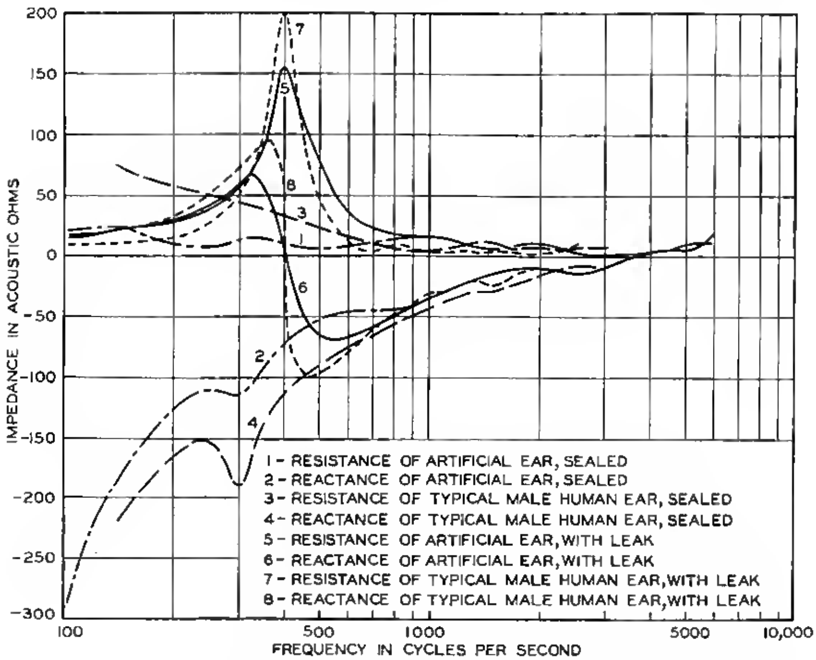


Fig. 13—Acoustic impedance of ears as viewed through aperture of receiver cap.

Considerably more data on human ears than are now available appear to be required before an artificial ear with more typical impedance characteristics than those shown can be designed.

In Fig. 14 additional acoustic impedance data on a typical male human ear and on the artificial ear are shown, the measurements in this case being made looking into the auditory canal. Table II presents data supplementing Fig. 14. As in the previous measurements, wide variations were encountered between different ears at any given frequency. The agreement between the artificial ear

TABLE II

ACOUSTIC IMPEDANCE OF EARS LOOKING INTO AUDITORY CANAL

f	Observed Range of Measurements for 7 Male Human Ears		Artificial Ear	
	Resistance	Reactance	Resistance	Reactance
200....	50 to 250	−1134 to −633	60	−610
400....	20 to 250	− 760 to −254	80	−385
800....	35 to 136	− 300 to −130	15	−145
1200....	60 to 91	− 180 to −20	20	− 80
2000....	8 to 70	− 155 to −50	20	− 27
3000....	15 to 60	− 140 to +50	22	+ 15

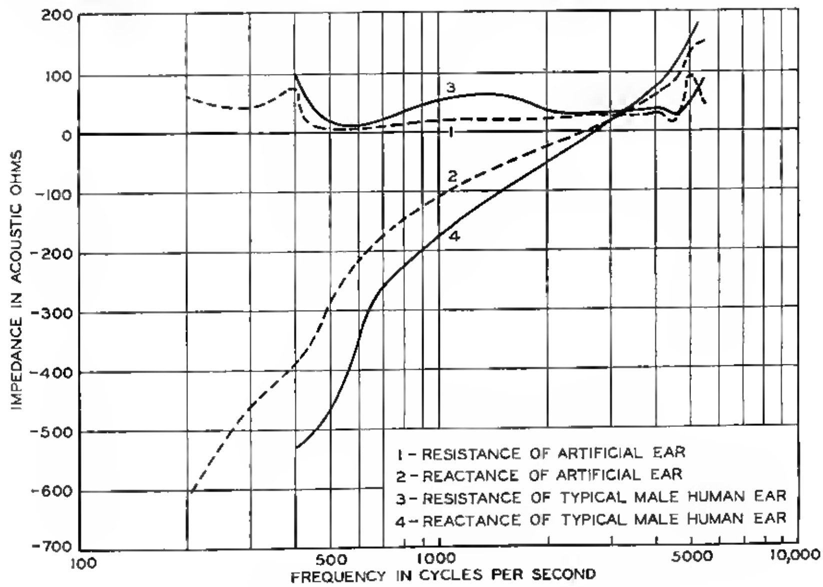


Fig. 14—Impedance characteristic of auditory canal.

results and the human ear measurements is as close as seems warranted by the available data.

The acoustic impedance data presented are important from the standpoint of insuring that the receiver under test on the artificial ear operates under nearly the same load conditions as it does on a human ear. It is also important that the response-frequency characteristic of a receiver obtained on the artificial ear compare well with that obtained on the human ear. In this connection two widely different types of receiver have been studied; one, a moving coil receiver such as is used in the Master Reference System for Telephone Trans-

mission,[8] and the other, a deskstand type receiver. Measurements of the response characteristics of these two types of receiver have been made on male human ears as described in the Appendix. The results obtained, together with similar measurements on the same receivers on the artificial ear, are shown in Figs. 15 and 16. Over most of the frequency range rather good agreement is found between the human ear and artificial ear measurements, the discrepancies in most cases being relatively unimportant.

Electrical impedance measurements were made on two commercial types of receiver whose impedances at resonance are relatively sensitive to changes in acoustic load. These measurements were made with

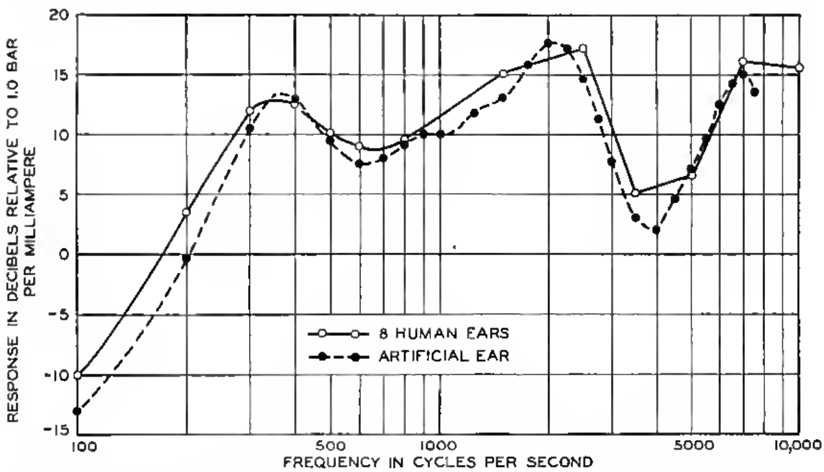


Fig. 15—Response-frequency characteristic of moving coil receiver on ears.

the receiver in free air and when held to the human ear and to the artificial ear. The results are shown in Table III. The values of

TABLE III
Electrical Impedance Data for Different Types of Receivers with Various Loads

Load Condition	Type of Receiver	Natural Frequency (f_0)	Damping Constant (Δ)
Air	Deskstand	854	122
Artificial Ear	"	1009	208
Observed Range on Male Human Ears	"	777–1062	141–258
Air	Handset	808	122
Artificial Ear	"	967	355
Observed Range on Male Human Ears	"	818–1048	226–524

[8] "Master Reference System for Telephone Transmission," W. H. Martin and C. H. G. Gray, *Bell System Technical Journal*, July, 1929.

natural frequency (f_0) and damping (Δ) as obtained from motional impedance circles for the measurements on human ears vary over a wide range. The results obtained on the artificial ear closely approximate those obtained on what may be considered a typical normal male ear.

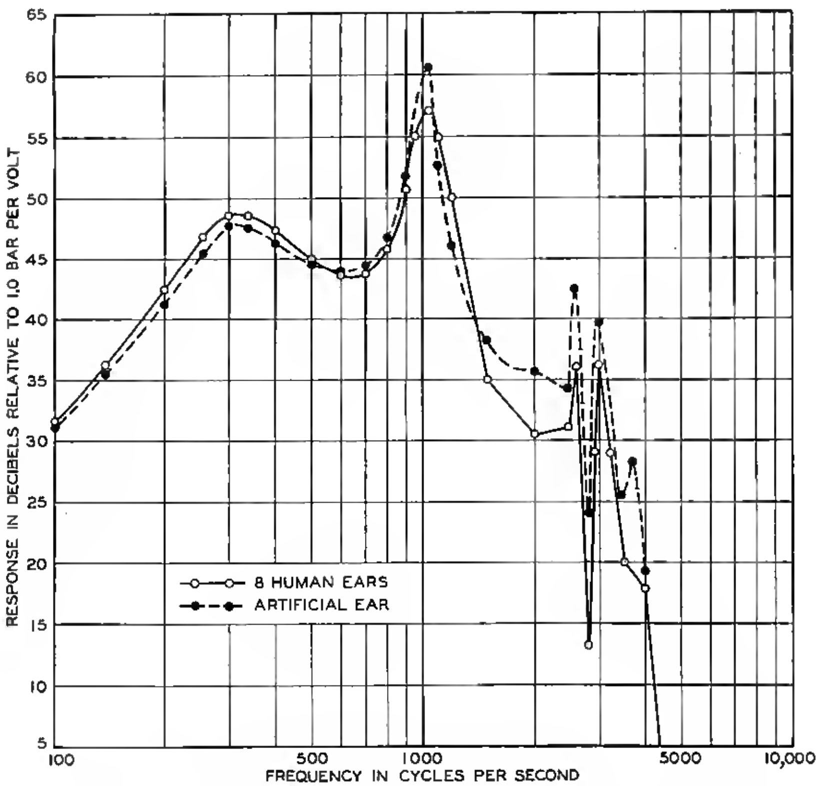


Fig. 16—Response-frequency characteristic of deskstand receiver on ears

The artificial ear coupled through a suitable amplifier is terminated in measuring apparatus similar to that employed in the sound meter.[9] The indicating instrument used responds to impulses of short duration (under .2 second) in a manner approximating the response of the actual ear to sounds of similar duration. The rectifier, of the copper-oxide type, obeys over its useful range, essentially a square law. By the addition of a suitable loudness weighting network similar to

[9] "Indicating Meter for Measurement and Analysis of Noise," T. G. Castner, E. Dietze, G. T. Stanton, and R. S. Tucker. Presented at the Northeastern District Meeting of the A. I. E. E., Rochester, N. Y., April 29–May 2, 1931.

that used in the sound meter, the artificial ear may be used to obtain a measure of the relative loudness produced by different receivers. Other weighting networks may be used to enable a direct meter reading of other desired characteristics.

While any single design of artificial ear can, of course, simulate only a single ear condition, there appears to be no reason why a structure of the type described cannot be made to simulate any ear by proper changes in the dimensions of the passage and values of the acoustic impedances without sacrifice of stable performance or the ability to specify and reproduce it. As far as data on the characteristics of human ears are at present available, the particular design described gives a good approximation, both in its effect on the receiver and in its own frequency characteristics, of a typical male ear. There is indication that this artificial ear, in addition, may offer an equally satisfactory substitute for the real ear in the measurement of open sound fields. A further study of this possibility is being made.

General Applications of the Artificial Voice and Ear

Equipment of the kind described offers many advantages, both in aboratory investigation and in shop testing of instruments, as compared with the methods that have been used heretofore. The artificial voice and ear described have, of course, the advantages of exact specification and control of the testing conditions, and of rapidity in obtaining data which have been the principal arguments for the use of previous voice and ear substitutes. In addition, instruments tested by these new means are under nearly normal operating conditions.

In laboratory investigations and development of instruments the artificial voice, makes it possible to carry out tests, such as response-frequency measurements with the same instrumentalities as are used for speech tests. This is, of course, impossible with the real voice. When used in conjunction with a high quality transmitter it permits either the variation of talking intensity without change in quality, or the maintenance of a constant output intensity from the artificial mouth, even though the actual speaker's voice may be varied over a wide range. Applications of this kind in exercising over a caller's voice, control of which he himself is incapable, are invaluable in many laboratory investigations.

As applied to shop inspection practices, the desirability is obvious of having a single testing means for all transmitters and receivers regardless of type, which is identical in principle with the means of testing used in the laboratory. The results of measurements made on instruments, whether in laboratory, factory or repair shop, can be

directly compared and the results used to great advantage in the engineering and maintenance of the telephone plant.

A further valuable application of the artificial voice and ear is as an adjunct to a reference telephone system. At the present time uncontrollable differences in technique and testing personnel at various points where it may be desirable to employ such reference systems involve discrepancies difficult to eliminate or explain. The use of the artificial voice and ear with suitable phonograph records makes it possible to have identical testing means at any point desired.

Further experience with the artificial voice and ear will undoubtedly open up new possibilities and applications for these instrumentalities and enable more accurate investigation of instruments with less expenditure in effort and time.

APPENDIX

Response-Frequency Characteristics of Receivers on the Human Ear

In Figs. 15 and 16 are shown response-frequency characteristics of receivers on the human ear. One method by which such characteristics may be determined is shown schematically in Figs. 17-*A* and 17-*B*. With the auricle projecting through an aperture (provided for purposes of definite location of the ear) toward the sound source as shown, the pressure at each frequency produced at the tympanum or as near to it as possible is measured by means of the calibrated transmitter and search tube.

With the pressure measured and the search tube removed from the ear, the observer listens to the sound from the source, as shown in Fig. 17-*Ba*. Then he listens to the receiver to be calibrated as shown in Fig. 17-*Bb*. The electrical input to the receiver is adjusted until the observer judges the sensation to be equal to that from the source. This then gives the pressure produced by the receiver for a given frequency and for a given input to the receiver.

The Search Transmitter and Its Calibration

The purpose of the search transmitter is to furnish an instrument of small external dimensions to meet the following requirements:

1. It must admit of calibration at single frequencies in terms of electrical output per unit pressure at the mouth of the tube.
2. It must be small enough to admit of insertion into the ear canal without material distortion of the sound field in the latter.

The tube used in the measurements is associated with a condenser transmitter.[6] One end of this tube, having a relatively large opening is acoustically coupled to the transmitter diaphragm. The calibration of the transmitter is made with the aid of a Rayleigh Disc, in a highly damped sound-proof box, as shown in Fig. 18. The sound source is a loud speaking receiver of large power capacity,[4] terminated with an

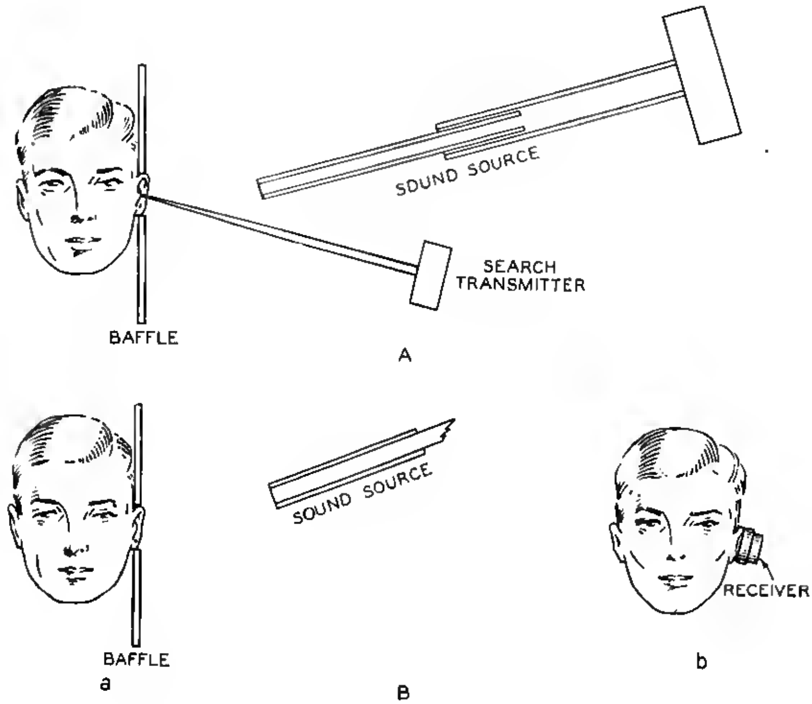


Fig. 17—Diagrammatic arrangement employed in receiver calibrations on human ears.

adjustable tube. With the mouth of the tube as origin, an approximately spherical progressive sound wave is produced. From the disc deflection, the particle velocity and hence the alternating sound pressure is determined in the space occupied by the disc. The search transmitter (the bulk of it wrapped in felt) is placed with its mouth as near the disc as possible, and its voltage output is measured.

The search transmitter calibration is made under conditions conforming to the following essential requirements:

[6] Loc. cit.
[4] Loc. cit.

(*a*) The presence of the search transmitter does not appreciably affect the deflection of the disc.

(*b*) The output of the transmitter is determined solely by the position of the mouth of the tube in the sound field; i.e., it is independent of the angle at which the tube may be pointing, and of any rotation about its axis.

(*c*) The output of the transmitter with the mouth of the tube closed must be small compared to that with the mouth open.

(*d*) The form of the sound wave must be such that the relation between the velocity and pressure at the mouth of the tube is known.

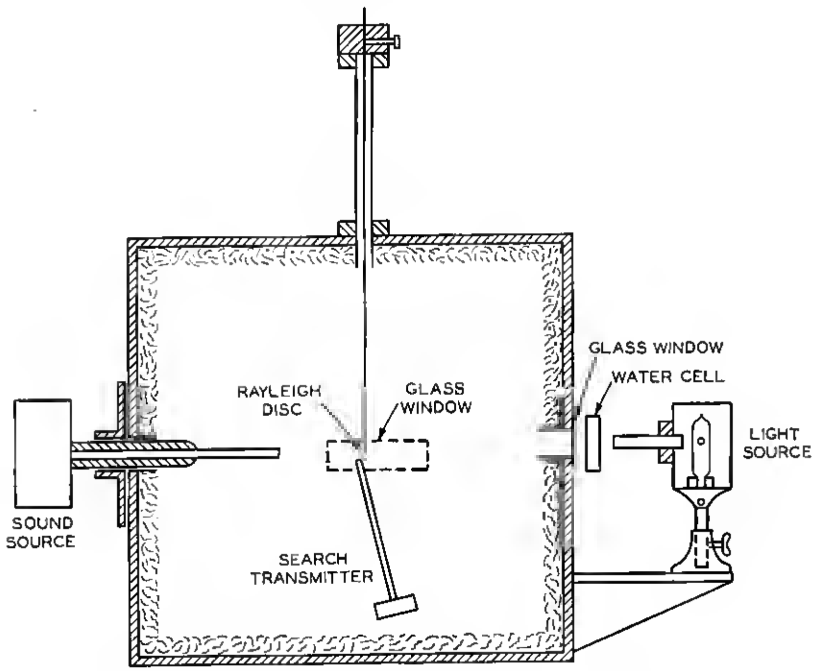


Fig. 18—Search transmitter calibration by means of Rayleigh disc.

Measurement of Pressure in Ear Canal Without Receiver

Pressure measurements are made as far inward in the canal as consistent with perfect safety to and comparative comfort of the subject. Most ears show a distinct bend in the canal accompanied by a flange which is mainly responsible for obstructing the view of the tympanum. It has been found possible to make measurements at a distance of from 0.5 cm. to 1 cm. past that flange, toward the tympanum. It is doubtful if measurements can be made at a point

much closer when all circumstances are considered, e.g., the frequency range to be covered and the importance of incurring no risks whatever.

The region inward beyond this bend is apparently one of rather uniform pressure, usually higher than in the outward positions of the canal, so that there is little chance of a measurement being made at the pressure node of a distinct standing wave pattern. This probably is accounted for by the irregularity of the passage and the character of the canal walls.

Receiver Calibration

At each frequency, response measurements were made on eight ears as described, and the average computed. The results are shown in Fig. 15.

When the response-frequency characteristic of one receiver has been determined by the method described, any other receiver may be calibrated by a direct comparison. The response-frequency characteristic on the ear shown in Fig. 16 was obtained in this manner.